



Run 2 Beauty Physics at DØ

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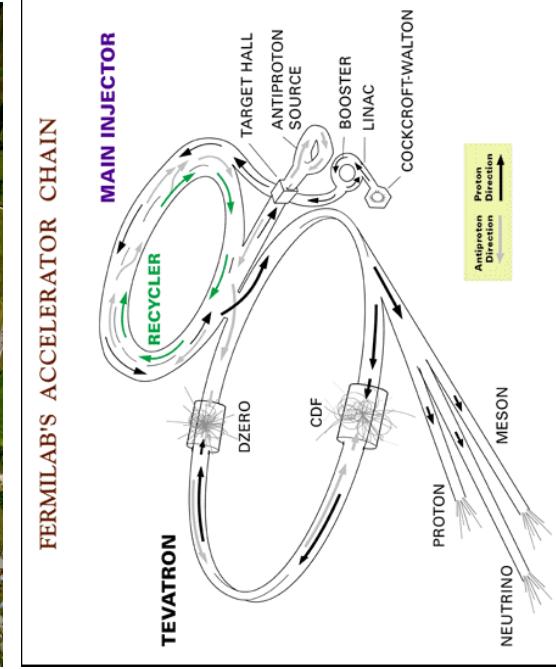
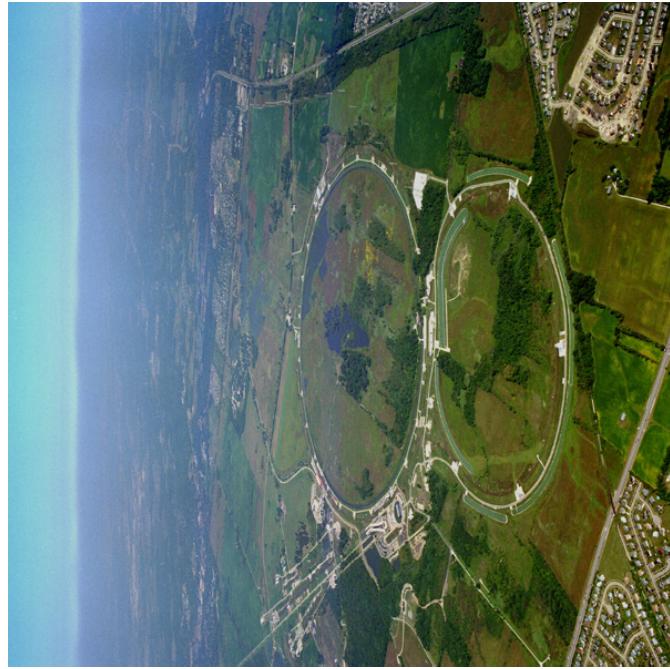
1. Introduction
2. DØ in Run 2
3. B physics in Run 2

B-physics at Hadron Machines - BEAUTY2002

June 17-21, 2002

Introduction

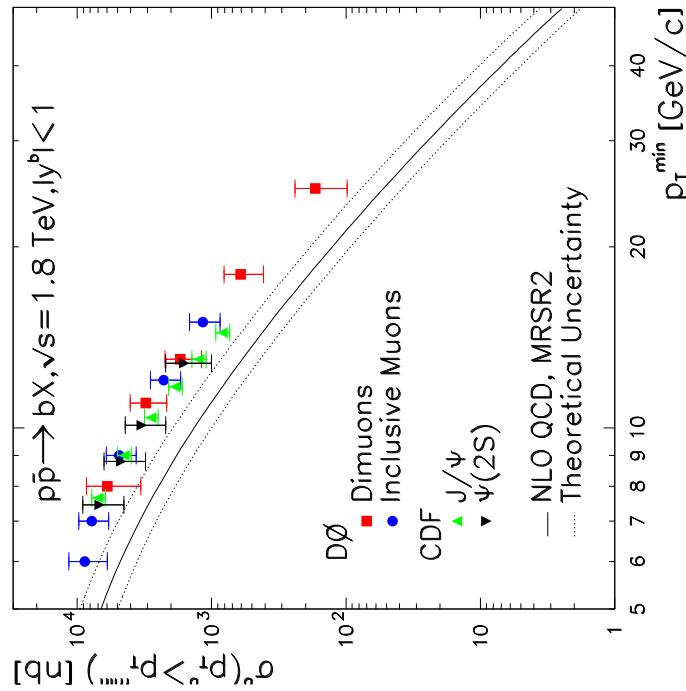
- ◆ DØ is an international collaboration of ~ 600 physicists from 18 nations
- ◆ DØ is a collider detector at the Tevatron
- ◆ Physics program: Higgs, Weak bosons, top quark, QCD, B physics, new physics (supersymmetry, extra dimension, etc.)



The Tevatron is a B factory

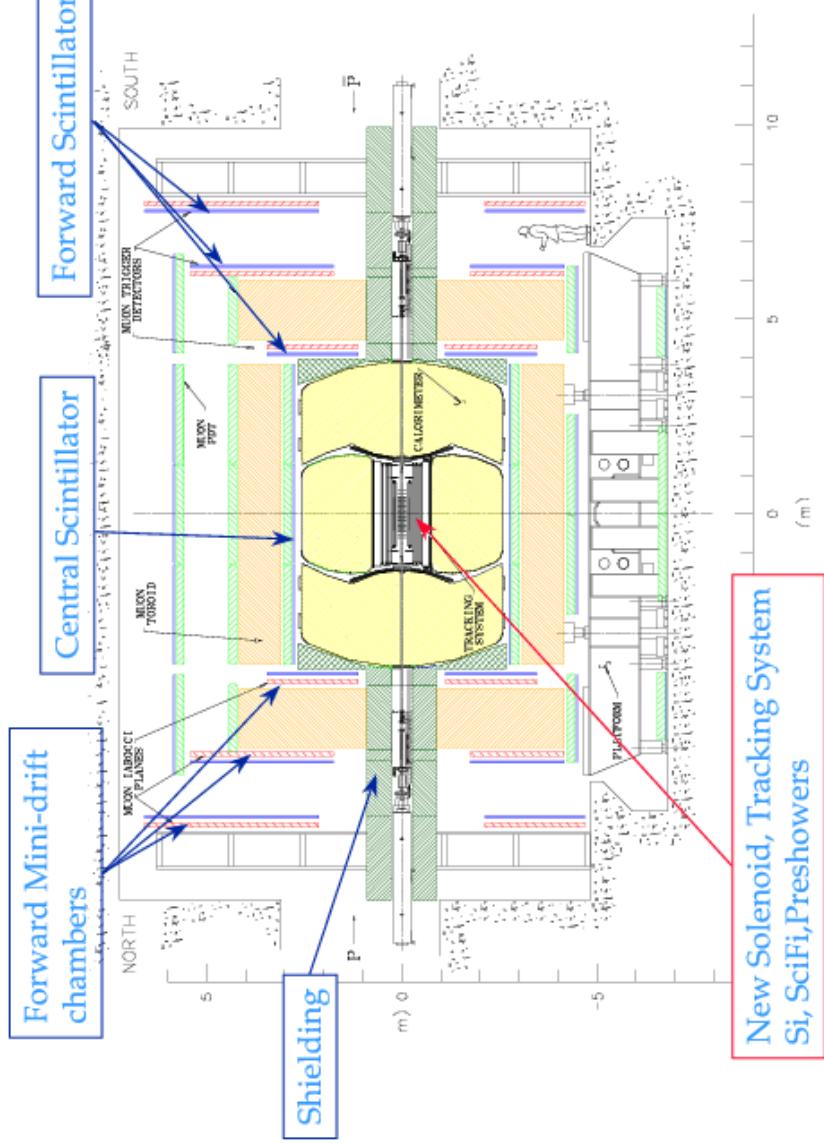
- ❖ Large production cross section
- ❖ All species, including B_s, B_c, Λ_b are produced
- ❖ $D\bar{\varnothing}$ capabilities
 - ❖ Single lepton trigger
 - ❖ Di-lepton triggers
 - ❖ Track trigger at Level 1
 - ❖ New tracking systems
 - ❖ Precise 2nd vertex reconstruction
 - ❖ Increased muon coverage

$\sigma(p\bar{p} \rightarrow b\bar{b})$	\approx	$150\mu b$ at 2 TeV
$\sigma(e^+ e^- \rightarrow b\bar{b})$	\approx	$7nb$ at Z^0
$\sigma(e^+ e^- \rightarrow B\bar{B})$	\approx	$1nb$ at $\Upsilon(4S)$



The Upgraded DØ Detector

- ❖ Inner tracking (silicon and fiber):
- ❖ Momentum resolution:
 $d p_T / p_T^2 = 0.002$
- ❖ Vertex Reconstruction:
 - ❖ primary vertex:
 $\sigma = 15 - 35 \mu\text{m} (\mathbf{r} - \varphi)$
 - ❖ secondary vertex:
 $\sigma = 40 \mu\text{m} (\mathbf{r} - \varphi), 80 \mu\text{m} (\mathbf{r} - \mathbf{z})$
- ❖ Excellent calorimetry with fast readout
- ❖ Muon system with better μ -ID
- ❖ Excellent trigger coverage for leptons:
 - ❖ muons: $p_T > 1.5 \text{ GeV}, |\eta| < 2$
 - ❖ electrons: $p_T > 1 \text{ GeV}, |\eta| < 2.5$

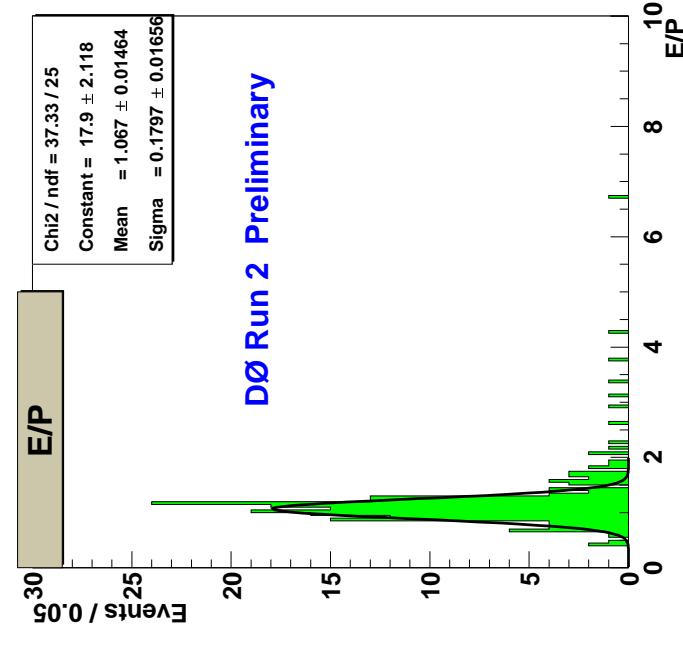
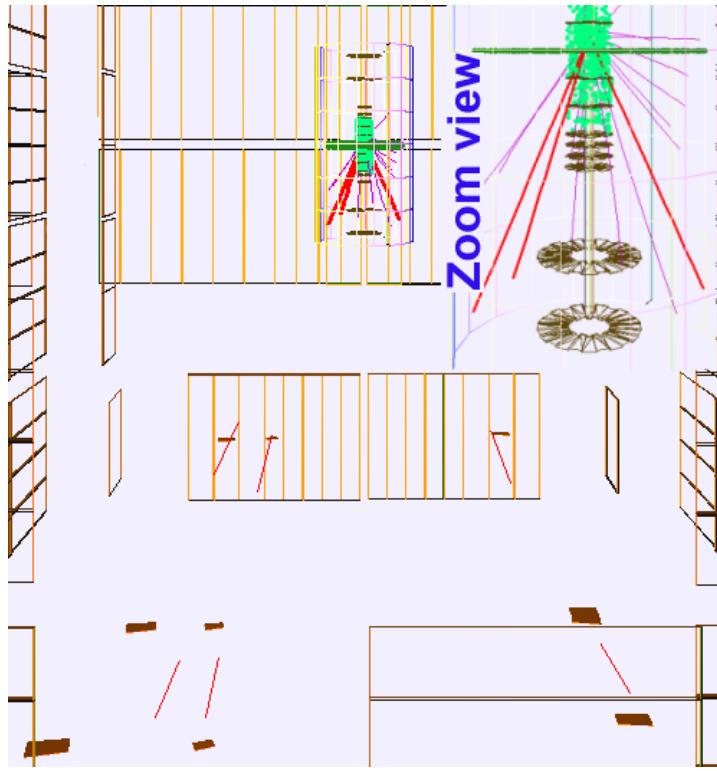


The $D\bar{\phi}$ – Tracking

- ♦ Silicon Microstrip Tracker (SMT)
 - ✧ Four layer barrels
(single/double sided)
 - ✧ interspersed double sided disks
 - ✧ 793,000 channels
 - ♦ Central Fiber Tracker (CFT)
 - ✧ 16 layers of sci-fibers
 - ✧ 77,000 channels
 - ♦ Solenoid
 - ✧ 2T super-conducting
 - ♦ Central Preshower
 - ✧ Scintillator strips
 - ✧ 8,000 channels
 - ♦ Forward Preshower
 - ✧ Scintillator strips
 - ✧ 16,000 channels
- 100% commissioned
- Six barrels: 93% operational
- Twelve F-disks: 96% operational
- Four H-disks: 89% operational
- Fiber Tracker Electronics 100% installed and operational by April 2002
-
- The diagram illustrates the DØ detector's layout. It features a central fiber tracker (CFT) surrounded by a solenoid. Outside the solenoid are two central preshower systems and a central calorimeter. Forward preshower systems are located on either side of the central components. The entire assembly is housed within a rectangular frame labeled "50 cm". The diagram also shows the forward preshower, central fiber tracker, central preshower, solenoid, calorimeter, and forward calorimeter. The regions are labeled with pseudorapidity ranges: $\eta=1.0$, $\eta=2.0$, and $\eta=2.5$. A "Lumi. Monitor" is shown at the top right.

DØ Calorimeter and Muon System

- ◆ Preserve excellent Run 1 performance
- ◆ Uniform, hermetic, coverage $|\eta| < 4.2$
- ◆ 100% commissioned
 - ◆ $\sim 55K$ readout channels
 - ◆ $\sim 0.1\%$ dead/noisy
- ◆ Good energy resolution
- ◆ Coverage to $|\eta| < 2$
- ◆ Forward and central sub-systems
- ◆ Good time resolution ~ 2.5 ns of trigger scintillators to remove out-of-time background



DØ Trigger and DAQ systems

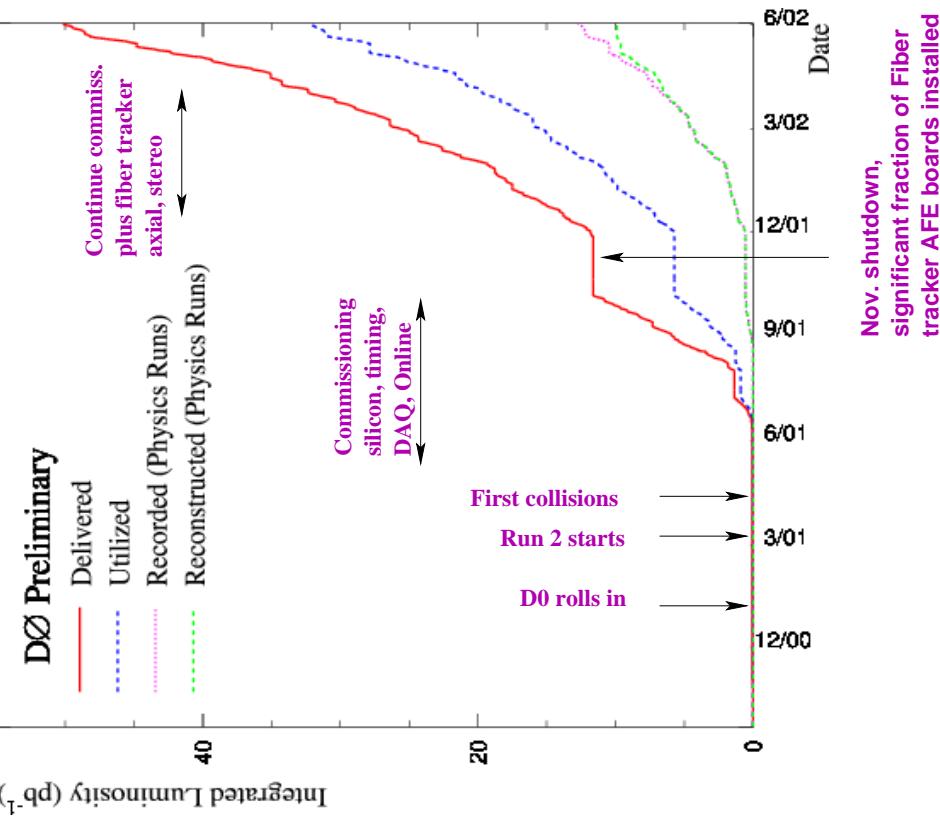
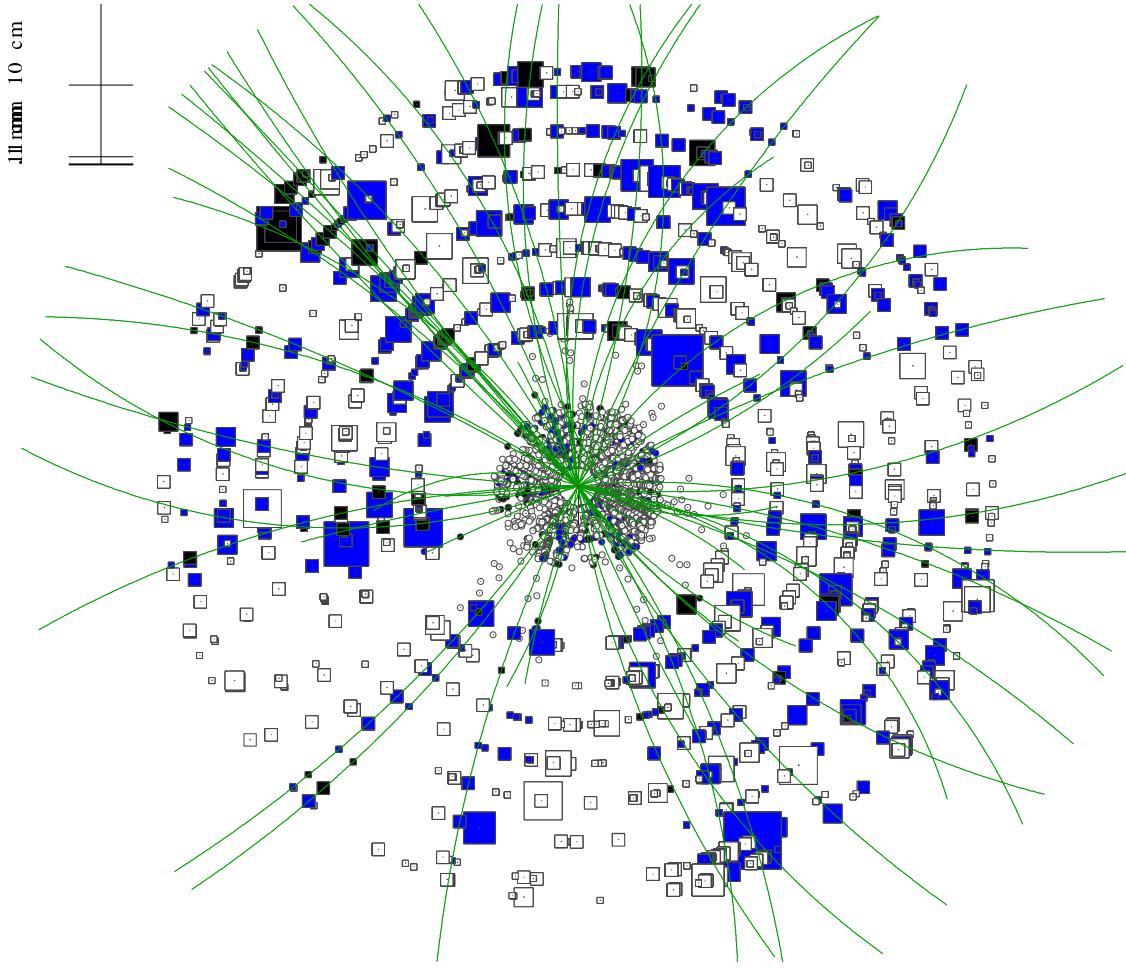
DØ solution

- ◆ Data to handle in Run 2a
 - ◆ Bunch crossing spacing @396 nsec
 - Every second DØ must choose 50 interesting events out of 2.5 millions beam crossings
 - ◆ Data rate which can be written to tape
 - ◆ 250kB/event at 2.5MHz
625Gb/second !!
 - ◆ 250kB/event at 50Hz
12Mb/second more resonable
- ◆ Level 1 input rate $\sim 2.5\text{MHz}$, output rate $\sim 5\text{kHz}$ with $\sim 5\%$ deadtime
 - ◆ fast hardware and firmware based trigger
 - ◆ calorimeter and muon system triggers working well
- ◆ Level 2 input rate 5kHz , output rate 1kHz
 - ◆ Alpha's fast processor running Linux
 - ◆ firmware and software trigger
- ◆ Level 3 input rate 1kHz , output rate 50Hz
 - ◆ use 48 Linux nodes
 - ◆ software trigger

Level 1 Central Track Trigger and Level 2 Silicon Track Trigger are coming this summer/fall

DØ in Run 2

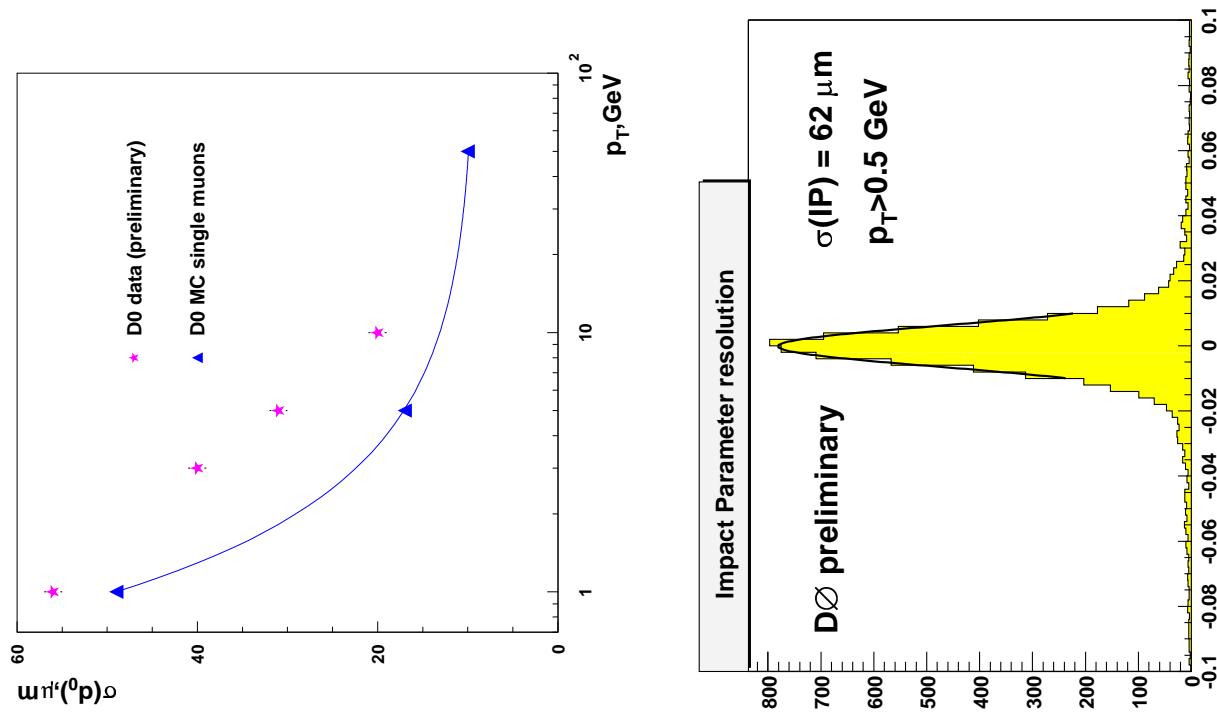
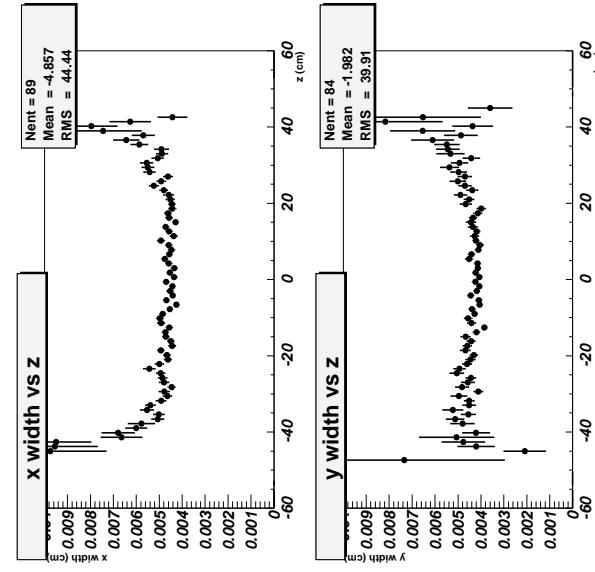
Run 151911 : Event 26747963



Tracking performance

- ❖ Beam spot measurements: $30 \pm 3 \mu\text{m}$
- ❖ IP resolution in data is close to MC
 $\sigma(\text{IP}) = 62 \mu\text{m}$
- ❖ Vertex resolution
 $\sigma_{r-\varphi}^{vtx} \sim 15 - 35 \mu\text{m}$ (MC)
 $\sigma_{x,y} \sim 35 \mu\text{m}$ (DATA)

Vertex width



We're approaching our MC performance predictions

D $\bar{\mathcal{O}}$ B Physics Program

QCD tests \Rightarrow cross sections, correlations, charmonium polarization

CP Violation \Rightarrow $B \rightarrow J/\Psi + K_s$ $\sin(2\beta)$
 \Rightarrow $B_s \rightarrow J/\Psi \phi$ (non SM)

B_s mixing \Rightarrow semi-leptonic ($B_s \rightarrow D_s^- \ell^+ \nu X$)
hadronic ($B_s \rightarrow D_s + n\pi$) modes

Spectroscopy \Rightarrow ($B^0, B^+, B_s, B_c, \Lambda_b$), double heavy baryons
and Lifetimes

Rare decays \Rightarrow $B_s \rightarrow D_s^{*+} D_s^{*-}$, $B \rightarrow \ell^+ \ell^-(X)$, $B_s \rightarrow K^* \gamma$

Flavor Tagging

Opposite side tags:

✗ Identify the flavor of the other B:

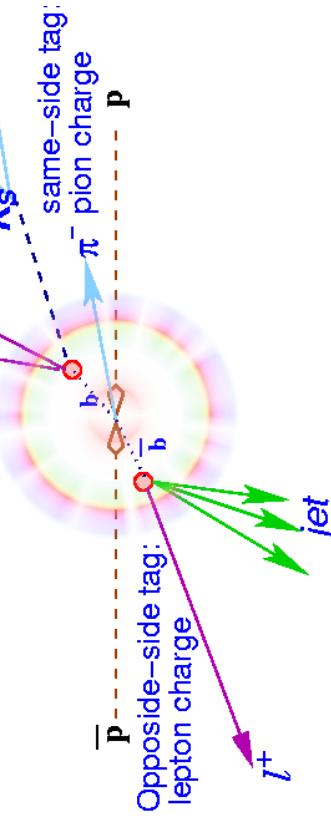
- ❖ soft lepton tags $b \rightarrow \ell^- + X$

- ❖ jet charge tags $Q_{jet} < 0$ for b

Same side tags:

✗ Correlation of flavor and charge of closest particle produced in fragmentation or decay

Example $B^0 \rightarrow J/\Psi K_s$ reconstruction



- ❖ Measure decay length
- ❖ Tag flavor at production
 - ❖ SST – pion charge
 - ❖ OST – lepton and jet charge

Flavor Tagging (projection from Tevatron report)

Tag	$\varepsilon D^2(\%)$ measured	$\varepsilon D^2(\%)$ expected	Relevant $D\bar{\varnothing}$	$\varepsilon D^2(\%)$ $D\bar{\varnothing}$
CDF Run I	CDF Run 2	CDF Run 2	difference	capabilities
same side	$1.8 \pm 0.4 \pm 0.3$	2.0	same	2.0
soft lepton	$0.9 \pm 0.1 \pm 0.1$	1.7	μ, e ID coverage	3.1
jet charge	$0.8 \pm 0.1 \pm 0.1$	3.0	forward tracking	4.7
opp. side	2.4	no K id	none	
combined	9.1			9.8

$\sin(2\beta)$ Expectation for 2 fb^{-1}

For a time dependent analysis:

$$\sigma(\sin 2\beta) \approx e^{x_d^2 \Gamma^2 \sigma_t^2} \sqrt{\frac{1 + 4x_d^2}{2x_d}} \frac{1}{\sqrt{\varepsilon D^2 N}} \sqrt{1 + \frac{B}{S}}$$

Run 2 @ D \bar{Q} :

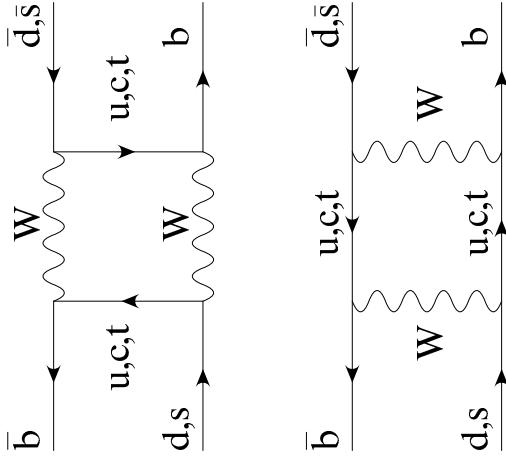
- ⌚ $\mathcal{L} = 2 \text{ fb}^{-1}$
- ⌚ $S/B \simeq 0.75$
- ⌚ $(\varepsilon D^2)^{tag} \simeq 9.8\%$
- ⌚ Time resolution $\sigma_t \simeq 100 \text{ fs}$

	mode	$J/\Psi \rightarrow \mu\mu$	$J/\Psi \rightarrow ee$
trigger eff(%)	27	20	
reco'd events	40,000	30,000	
$\delta(\sin 2\beta)$	0.04	0.05	
combined		0.03	

D \bar{Q} and CDF have similar precisions

$B_{d,s}$ Mixing

- ❖ Weak eigenstates \neq mass eigenstates
- ❖ Mixing due to higher order corrections
- ❖ $\mathcal{P}_{\text{mixed}}(t) \propto \cos \Delta m_q t / \cosh(\Delta \Gamma_q t / 2)$
- ❖ $\Delta m_q = m_{B_{\text{heavy}}^0} - m_{B_{\text{light}}^0} \propto |V_{tb} V_{tq}|^2$
- ❖ Measure $x_q = \frac{\Delta m_q}{\Gamma_q}$, $y_q = \frac{\Delta \Gamma_q}{\Gamma_q}$ for $q = d, s$



In SM we have:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s^0}}{m_{B_d^0}} \xi_s^2 \left| \frac{V_{ts}}{V_{td}} \right|^2, \quad \xi_s \simeq \frac{f_{Bs}}{f_{Bd}} = 1.14 \pm 0.08$$

As the ratio $|V_{ts}/V_{td}|$ is large, the B_s oscillation frequency is thought to be much higher than the well measured B_d oscillation frequency

B_s Mixing at DØ (modes under investigation)

hadronic mode(s)

$$B_s^0 \rightarrow B_s \rightarrow D_s n \pi^+$$

$$D_s \rightarrow \phi \pi \rightarrow K K \pi$$

- ❖ hadronic modes require lepton from opposite b for trigger – sign gives initial flavor
 - ❖ final flavor tagged by charge of the D_s
 - ❖ no missing neutrinos
 - ❖ expect a few thousand events
- Can probe $x_s \leq 30$ in 2 fb^{-1}

semi-leptonic mode(s)

$$B_s^0 \rightarrow D_s^- \ell^+ \nu X$$

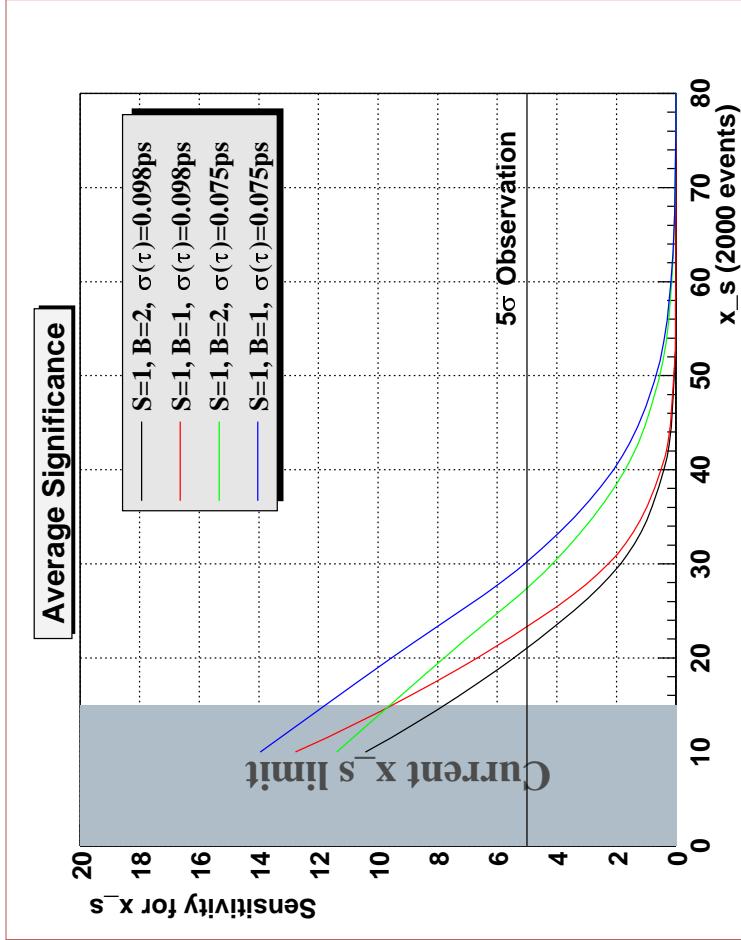
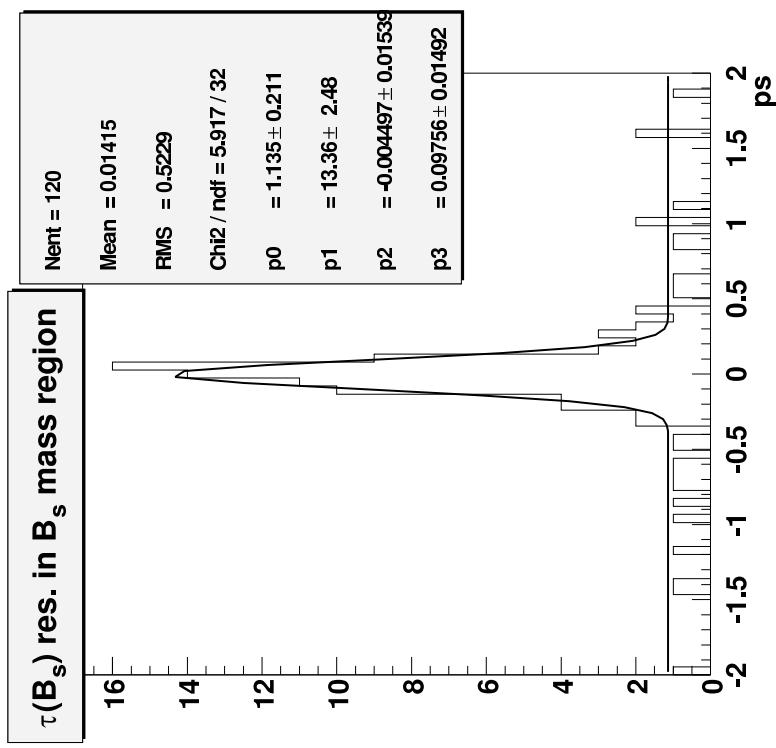
$$D_s^- \rightarrow \phi X$$

- ❖ trigger on dilepton events
- ❖ initial flavor tagged by opposite side lepton
- ❖ final flavor tagged by same side lepton

expect 40,000 blue events

B_s Mixing (hadronic modes)

$B_s \rightarrow D_s \pi^+$ with $D_s \rightarrow \phi \pi \rightarrow K \bar{K} \pi$

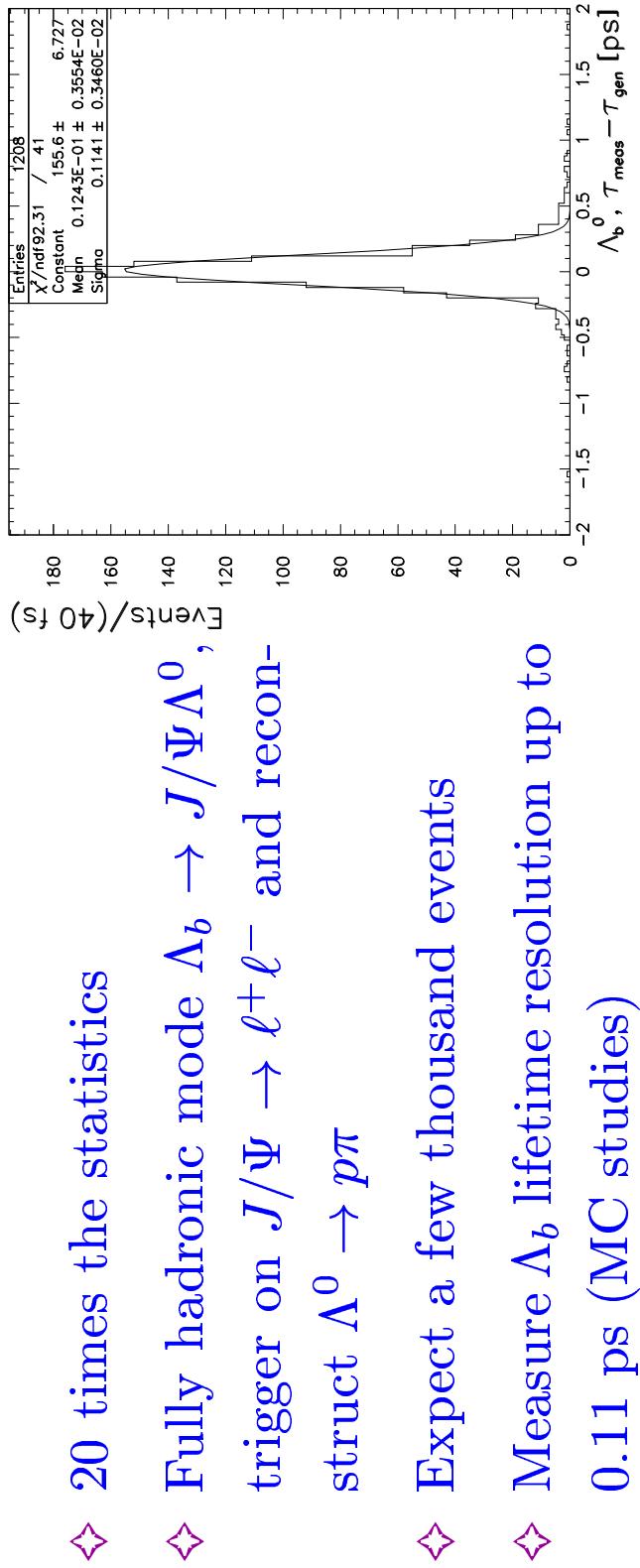


Very sensitive to $\tau(B_s)$ resolution, reach in x_s up to ~ 30

Looking for Λ_b 's

Motivation: existing discrepancy between the spectator model prediction ($\tau(\Lambda_b^0)/\tau(B^0) = 1$) and current data measurements, $\tau(\Lambda_b^0)/\tau(B^0) = 0.79 \pm 0.05$.

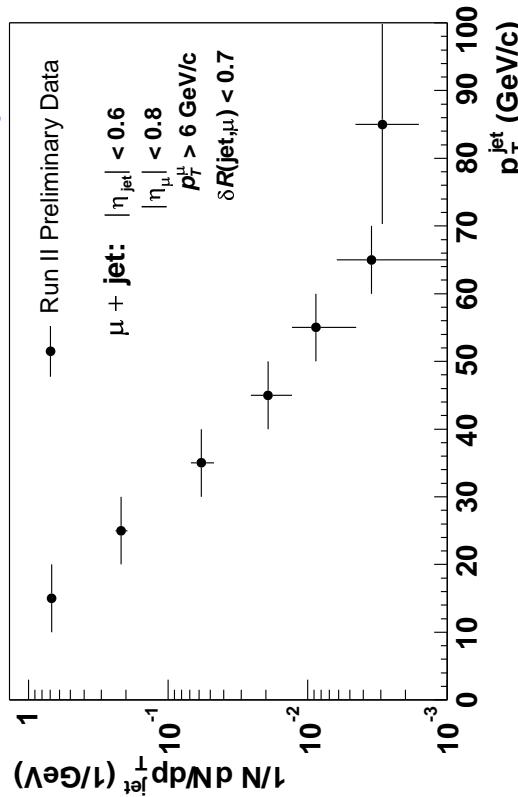
Λ_b 's in Run 2



B Physics in Run 2 (b cross-section)

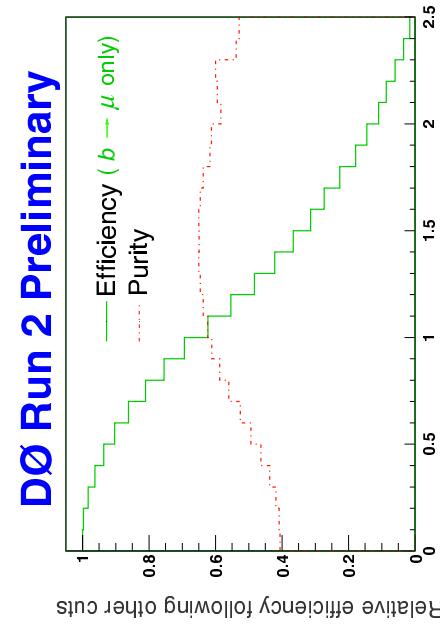
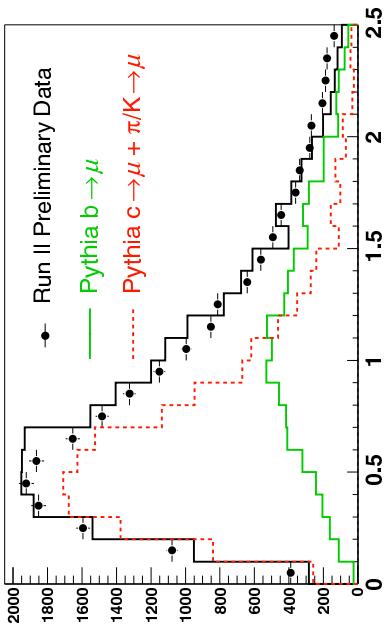
Normalized μ +jet differential cross-section
(data sample $< 0.2 \text{ pb}^{-1}$)
Trigger and reconstruction efficiencies and
jet energy scale corrections included

DØ Run 2 Preliminary



p_T^μ with respect to the jet axis is a good discriminant between direct $b \rightarrow \mu$ and background.

DØ Run 2 Preliminary



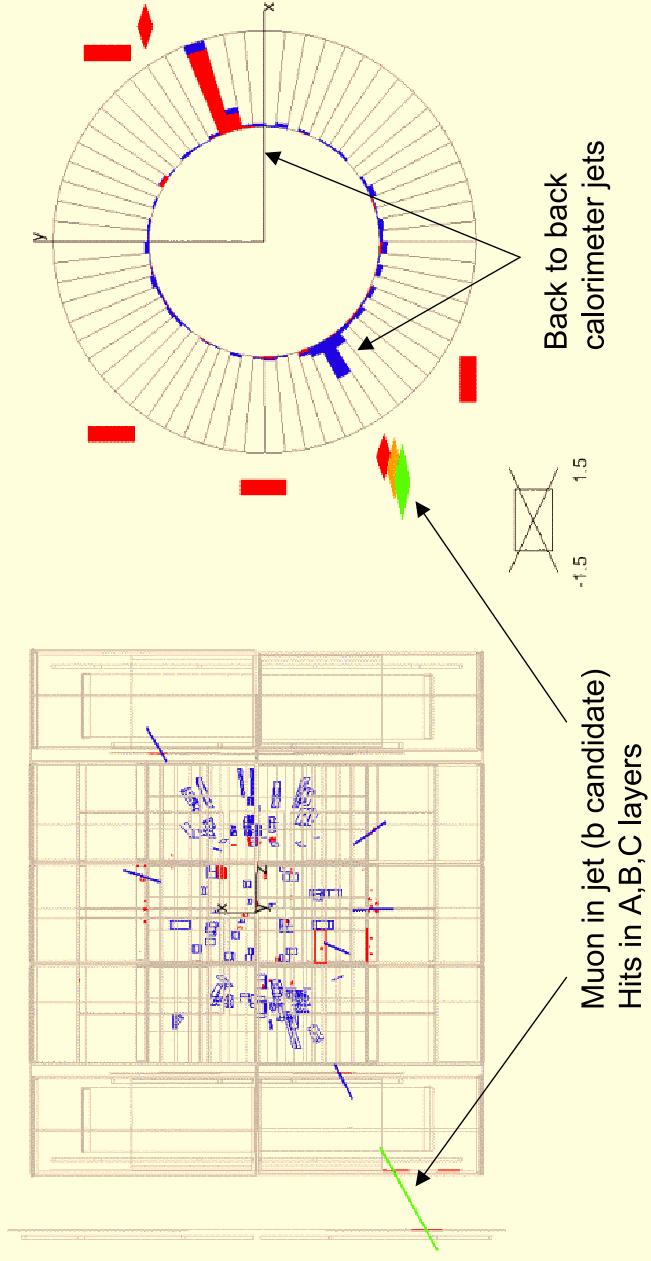
**Evidence for the b-content
in the μ +jet sample**

**Consistent in shape
with Run I results**

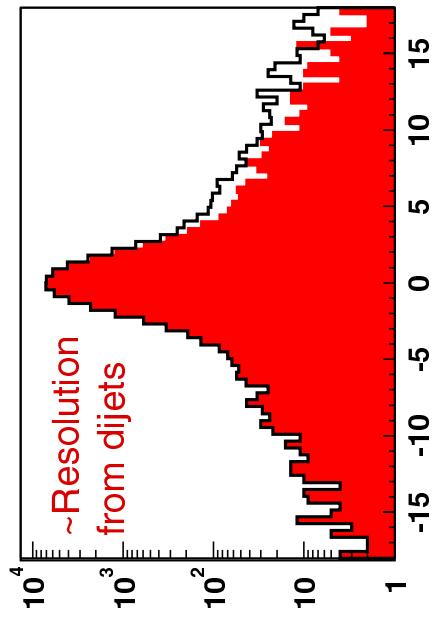
B Physics in Run 2 (μ +jet candidate)

Muons in Jets

ET scale: 19 GeV

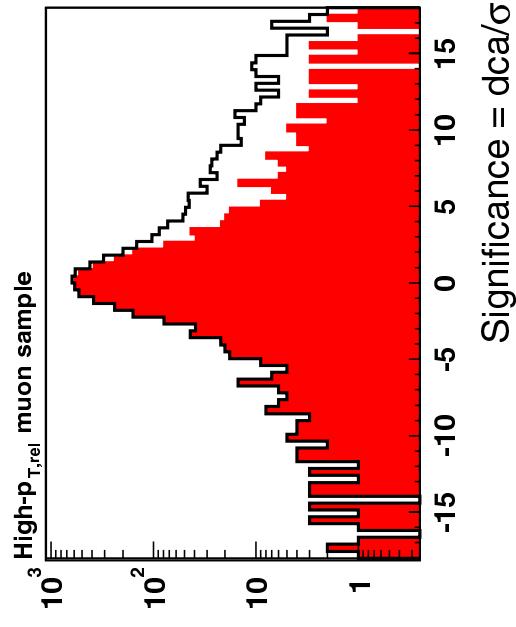


B Physics in Run 2 (B-tagging)



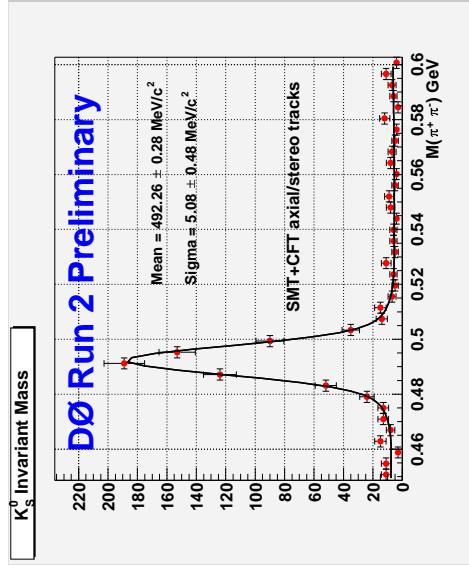
- ◆ Track $p_T > 1.5$ GeV
- ◆ 4 super layers in SMT and > 10 hits (SMT+CFT)
- ◆ $|dca| < 1.0$ mm (reduces K_s^0, Λ)

DØ Run 2 Preliminary

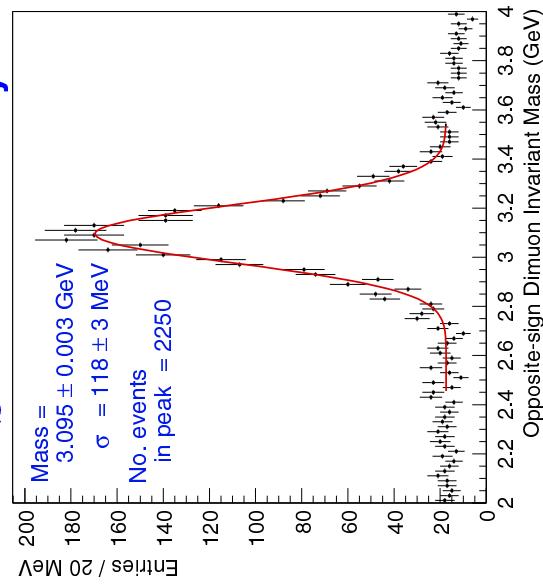
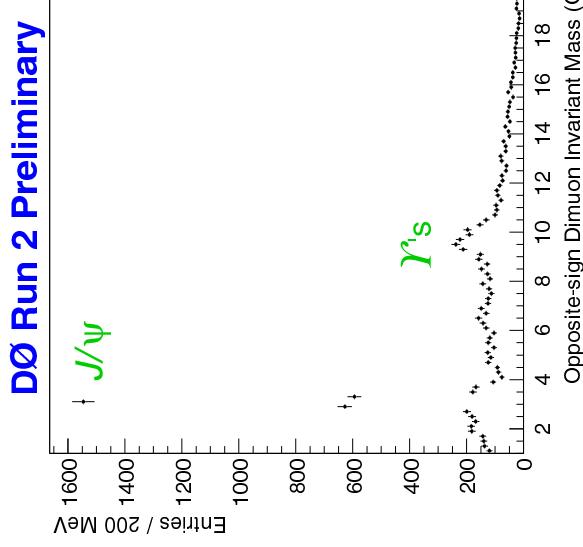


$p_T^{\text{rel}} > 1$ GeV (Enhanced in b-jet content)

B Physics in Run 2 (first steps towards $\sin 2\beta$)



- ◆ V0 finding algorithm is based on Kalman filter constrained vertex fit
- ◆ DATA: $\sigma(K_s) \sim 5$ MeV/c²
- ◆ we expect to improve J/Ψ mass resolution



Conclusion

- ◆ Data taking has been started
- ◆ $D\bar{\varnothing}$ ends commissioning step
- ◆ Performance of the detector close to the expectation
- ◆ B physics program is very encouraging
 - ❖ measure $\sin(2\beta)$ to an accuracy of 0.03
 - ❖ probe B_s mixing up to $x_s \sim 30$
 - ❖ rare decays: $B \rightarrow \ell^+ \ell^- K^*, K^* \gamma, \varphi \gamma$, etc.
 - ❖ full reconstruction of B_c decay modes
 - ❖ precision lifetime ratios ($B_s/B^0, \Lambda_b/B^0, B_c/B^0$)
 - ❖ many other topics ...
- ◆ First look at data, we see J/Ψ 's, K_s^0 's, Λ 's, Υ 's and much more